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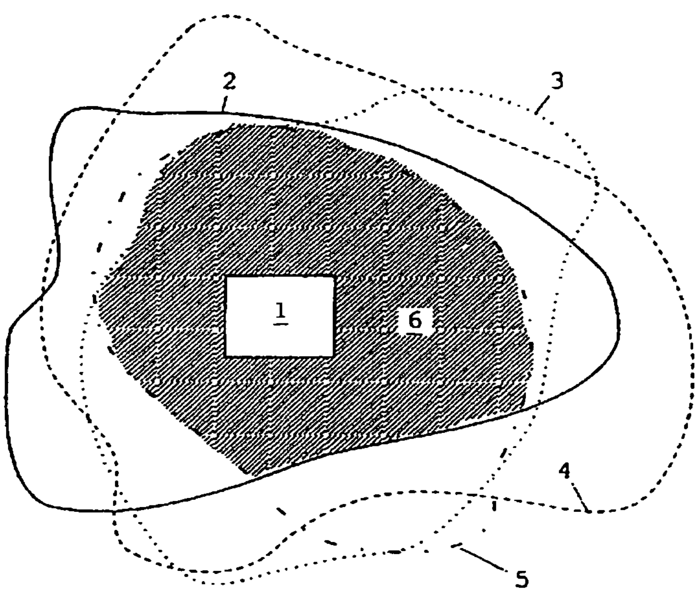
(54) Title: METHOD OF DEFINING NETWORK CELLS IN A COMMUNICATIONS NETWORK



(57) Abstract: The present invention relates to a method of communications network planning comprising the steps of: forming (8) a plurality of cells (6) depending on grade-of-service requirements for each cell, allocating (9) a base station (1) in each of said cells (6), assigning (10) traffic channels to each of said cells (6), assigning (12) frequencies to each of said cells (6). The step of forming (8) a plurality of cells (6) comprises the sub-steps of: determining (13) a power domain (2, $D^{(P)}$)(6), which includes all points for which the received power (P_r) is greater than a predetermined threshold power ($P_{r,th}$), determining (14) an snr domain (3, $D^{(snr)}$)(6), which includes all points for which the signal-to-noise ratio (snr) is greater than a predetermined threshold signal-to-noise ratio (snr_{th}), determining (15) a Shannon domain (4, $D^{(sh)}$)(6), which includes all points for which the channel capacity (C) is greater than a predetermined signaling transmission rate (R_g), determining (16) a BER domain (5D$^{(BER)}$)(6), which includes all points for which the error probability (P_e) is less than a predetermined error probability ($P_{e,th}$), creating (17) the cell (6) as an area of the intersection of the power domain (2, $D^{(P)}$), snr domain (3, $D^{(snr)}$) Shannon domain (4, $D^{(sh)}$), and BER domain (5, $D^{(BER)}$).

Method of defining network cells in a communications network

Field of the Invention

The present invention generally relates to the method of planning a cellular network, and in particular though not exclusively it relates to defining network cells in a high population urban area.

Background of the Invention

The method of cellular network planning is described in the patent application ... which is assigned to the assignee of the present invention and which is hereby incorporated for reference. The central problem of cellular network planning is the effective cell formation (CF), especially in a high population urban environment under pre-specified grade-of-service (GOS) constraints. The GOS is mainly determined by the quality and reliability of the communications in the network and cellular network planning (CNP) involves consideration of threshold values of the received signal power $P_{r,th}$ and signal-to-noise ratio snr_{th} (power GOS), error probability $P_{e,th}$ (information GOS). Key factors in high population urban areas (where traffic demand is concentrated) are propagation conditions of the electromagnetic waves (EMW) and distribution of communications channels in time.

In other words, the formation of network cells is essentially influenced by the EMW propagation conditions and by the expected traffic demand and occupation of channels of the network. In prior art methods of forming network cells the propagation conditions and the channel occupation are allowed for by simple statistical and stochastic models. Conventional cell formation procedures are based on various cell definitions. E.g. in WO 90/10342 "Method for planning radio cells" by Gunmar K. and in WO 93/15591: "Method and Apparatus for planning a cellular radio network by creating a model on a digital map adding properties and optimising

parameters, based on statistical simulation results", by Markus O. the cell is defined as an area within which the field strength of the base station exceeds a predetermined threshold value. The requirement of an acceptable signal-to-noise ratio is disclosed e.g. by Gunmar K. in US 5 307 510, "Method for determining the degree of coverage in the mobile radio system". In most of the works the classical definition of cell is used when the radio regions are designed in accordance to the distributions of the radio traffic density in the area of interest, e.g. in "The cellular concept", Bell. Syst. Tech. J., 58, (1), pp. 15-43, 1979, by MacDonald V. H. and in US 4 667 202 "Mobile radio network", by Kammerlander K. et al., and in US 5 465 390 "Method for laying out the infrastructure of cellular communications network", by Cohen R. and in US 4 759 051 "Communications system", by Han K. and in US 5 428 817 "Mobile communications system having variable coverage areas", by Yahagi M..

However, these simple models reflect the problems in realization of the network inadequately only and thus fail to provide optimum solutions in particular as to the formation of network cells.

Especially the conventional cell definitions do not allow for the reliability GOS constraint so that the conventional cell formation process is not optimal. As a result, the subsequent BER control in conventional cellular networks often requires an increased transmitted power or the repetition of the cell formation process with other system parameters (i.e. an iterative procedure). Further, the use of statistical models of EMW propagation and regular cell pattern of the area of interest (AOI) with the simplest cell shapes (triangular, rectangular, hexagonal) leads to overestimation of power, frequency and technical resources in conventional CF approaches due to an imperfect accounting for the above key factors that constraint the CF in high population urban areas. The low resolution of conventional DTM used in some approaches (about ten meters or higher) and the appropriate CF methods do not permit a high accuracy in high population urban environment. Interactive iterative procedures, used in some conventional CF approaches, become cumbersome and unrealistic for micro-cell network planning in large high population urban areas when the number of micro-cells is big enough (hundreds or more).

The problems of inadequate wave propagation models and channel stochastic become even more prohibitive in a network with micro-cells of a decreased cell size. e.g. of about 200m, which operate at low power of about 20mW with antennas located at lampposts etc.

The present invention seeks to enable a more accurate cell formation in such networks in order to mitigate or avoid the disadvantages and limitations of the prior art.

As a first aspect of the invention a cell formation method according to claim 1 is provided.

Another aspect of the invention is a communications network system with micro-cells in a high population urban environment as defined in claim 11.

The dependent claims are directed to preferred embodiments of the invention.

Preferred embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings.

Brief Description of the Drawings

Fig. 1 shows an example for the domains of which a cell according to this invention is formed.

Fig. 2 shows an explanatory diagram for the determination of contributions by electromagnetic wave reflections.

Fig. 3 shows an explanatory diagram for the determination of contributions by electromagnetic wave multiple reflections.

Fig. 4 shows an explanatory diagram for the determination of the effect of shadowing of electromagnetic waves.

Fig. 5 shows an explanatory diagram for diffraction effects of electromagnetic waves.

Fig. 6 shows an explanatory diagram for the determination of the basic contributions to a received signal by electromagnetic waves which are diffracted on side edges of a building.

Fig. 7 shows an explanatory diagram for the quantitative determination of reflection effects of electromagnetic waves.

Fig. 8 shows schematically the flowchart of an embodiment of the cellular network planning method according to the present invention.

Fig. 9 shows the step of forming a cell according to the present invention in detail.

Detailed Description of a Preferred Embodiment

The method of communications network planning according to the present invention comprises the steps of: forming a plurality of cells depending on grade-of-service requirements for each cell, allocating a plurality of base stations in the AOI, assigning traffic channels to each of said cells, assigning frequencies to each of said cells, wherein the step of forming a plurality of cells comprises the steps of: determining a power domain ($D^{(P)}$) for each cell, which includes all points for which the received power (P_r) is greater than a predetermined threshold power ($P_{r,th}$), determining an snr domain ($D^{(snr)}$) for each cell, which includes all points for which the signal-to-noise ratio (snr) is greater than a predetermined threshold signal-to-

noise ratio (snr_{th}), determining a Shannon domain ($D^{(sh)}$) for each cell, which includes all points for which the channel capacity (C) is greater than a predetermined signaling transmission rate (R_s), determining a BER domain ($D^{(BER)}$) for each cell, which includes all points for which the error probability (P_e) is less than a predetermined error probability ($P_{e,th}$), and creating the cell as an area of the combination of all of the power domain, snr domain, Shannon domain, and BER domain.

The communications network system according to the invention comprises a plurality of cells, wherein the size of each of the plurality of cells is determined by all of a power domain ($D^{(P)}$), a snr domain ($D^{(snr)}$), a Shannon domain ($D^{(sh)}$) and a BER domain ($D^{(BER)}$).

The CF problem is of particular practical interest for optimal micro-cellular radio network planning in an urban environment. Due to its efficiency the power, frequency and technical resources may be saved in the course of CNP, handoff operations are facilitated, and performance studies of the entire planned cellular radio network are enabled by highly accurate simulations which are based on a refined digital terrain model (DTM) which will briefly be discussed below.

In Fig. 1 an example of a cell 6 is shown which is constituted by the intersection of various basic domains, each being characterized by a specific parameter. In Fig. 1 a base station 1 is established at a location within the envisaged cell 6. The signal from this base station 1 will be received with a quality that varies with the location of the receiver (not shown). The quality of the received signal is expressed as "grade-of-service" (GOS), and areas with a satisfying GOS with respect to a specific parameter are shown in Fig. 1. E.g. the domain with a satisfying GOS as to the power of the received signal is designated by 2 and will be referred to in the following as power domain $D^{(P)}$; the domain with a satisfying GOS as to the signal-to-noise ration of the received signal is designated by 3 and will be referred to in the following as snr

domain $D^{(snr)}$; the domain with a satisfying GOS as to the channel capacity as opposed to the demand of traffic is designated by 4 and will be referred to in the following as Shannon domain $D^{(sh)}$; and the domain with a satisfying GOS as to the bit error rate (BER) of the received signal is designated by 5 and will be referred to in the following as BER domain $D^{(BER)}$.

According to the invention in a communications network system with a plurality of cells 6 as shown in Fig. 1 each cell is determined by the above domains 2, 3, 4, and 5. Thus, in general the size of each of the plurality of cells 6 is determined by all of a power domain 2 ($D^{(P)}$), a snr domain 3 ($D^{(snr)}$), a Shannon domain 4 ($D^{(sh)}$) and a BER domain 5 ($D^{(BER)}$).

In particular each of the plurality of cells 6 is formed as the intersection of said domains, such that each cell 6 corresponds to the intersection area of all of said power domain 2, $D^{(P)}$, said snr domain 3, $D^{(snr)}$, said Shannon domain 4, $D^{(sh)}$ and said BER domain 5, $D^{(BER)}$.

In the following the method according to the invention shall be described by which the determination of the domains and eventually of the cell is achieved, with reference to Fig. 2 to 9.

A flowchart for a software based on a method of communications network planning according to the present invention is shown in Fig. 8. The method comprises the steps of: reading all collected data on the specific network demands and the geographic particularities of the network area. These data are the basis for the planning procedure and are compiled in step 7 of the flowchart. In step 8 a plurality of cells 6 is formed depending on grade-of-service requirements for each of said cells 6. After the cell has been formed, in the general procedure in step 9 base stations 1 are allocated in the AOI, and in the following steps 10 and 12 traffic channels are assigned to each of said cells 6 and frequencies are assigned to each of said cells 6, respectively. In order to allow for long term changes of traffic demand in step 11 a query is performed whether or not new traffic data are available. If so, the procedure

branches back to the status immediately before the channel assignment in step 10 and the channel assignment is repeated so as to optimize the network efficiency in the whole. Else the frequency assignment in step 12 is carried out.

However, the above method is a rather rough approach, and the formation of the cells in step 8 remains the central problem of network planning. If therefore the planning is based on data with a rather poor resolution in the prior art the resulting network will be all but optimized.

According to the invention it is thus suggested to perform the following steps when forming said plurality of cells 6. These sub-steps are shown in Fig. 9. The flowchart of Fig. 9 is entered at step 13 (from step 7 in Fig. 8) and is continued (after step 17) by step 9 in Fig. 8. First, a brief overview of Fig. 9 will be given, the way of how to determine each of the domains will be described below.

For forming a cell 6 in a first sub-step 13 a power domain 2 $D^{(P)}$ is determined. The power domain $D^{(P)}$ includes all points of an area, for which the received power P_r is greater than a predetermined threshold power $P_{r,th}$.

In the next step 14 of the procedure an snr domain 3 $D^{(snr)}$ is determined. The snr domain $D^{(snr)}$ includes all points of an area, for which the signal-to-noise ratio snr is greater than a predetermined threshold signal-to-noise ratio snr_{th}.

In step 15 a Shannon domain 4 $D^{(sh)}$ is determined, which includes all points of an area for which the channel capacity C is greater than a predetermined signaling transmission rate R_s.

At last, in step 16 a BER domain 5 $D^{(BER)}$ is determined, which includes all points of an area for which the error probability P_e is less than a predetermined error probability $P_{e,th}$.

Eventually, in step 17 the domains 2 to 5 are intersected so as to form the desired cell 6. These above steps 13 through 17 of determining the domains and of intersecting them are repeated for all of said network cells 6. It will be understood that the above order of the sequence of steps 13 to 16 is not mandatory but can freely be chosen, being completed by step 17 in any case.

In other words, in the present invention the cell is defined as the intersection of power, snr, Shannon, and BER domains, each calculated for a given base station site in an area of interest. In the power domain the received signal power $P_r \geq P_{r,th}$; in the snr domain the signal-to-noise ratio $snr \geq snr_{th}$; in the Shannon domain the signaling transmission rate $R_s < C$, C being the Shannon channel capacity; and in the BER domain the bit error rate $P_e \leq P_{e,th}$ is calculated.

The above threshold values are preset before starting the planning procedure on the basis of the expected and desired characteristics of the communications network. Assessing and setting of threshold values is known to the one skilled in this art and will therefore not be explained here any further.

This cell definition allows optimization of the cell formation process and allows for the above GOS constraints just at the beginning of the cellular network planning. The exact calculation of the domains relies on the use of a high resolution model of the network geography. To that order a refined digital terrain model (DTM) of high resolution is used to provide the required high accuracy of cell formation and to account for key factors that determine cell formation in high population urban areas. With such a DTM a realistic radio channel model is used for the received radio signal represented as the sum of the deterministic and statistical parts. The former usually includes a few principal ray-theoretical components that mainly contribute to the total received signal power (about 90% or more), and may be predicted with high accuracy in each point of AOI via the DTM of high resolution by exact accounting for the main physical mechanisms of EMW propagation. The latter is the sum of signals of low power which forms the conventional Rayleigh fading signal. This channel model may

be considered as an extension of conventional Rice channel model to a few particular stable components in the received signal.

The main idea of the threshold domain method is to obtain directly highly accurate boundaries of the cell components by operating in a vector format of DTM, thus avoiding the bulky point-to-point calculations for formation of the cells.

In the following a detailed description of the determination of the domains will be given.

The power domain 2 $D^{(P)}$ is one of the cell components that follows from the above extended cell definition. This domain corresponds to the power GOS constraint $P_{r,th}$ (a power threshold of the received signal) with a given base station 1 of the co-ordinates $M_0 = (x_0, y_0, z_0)$. The domain is defined as

$$D^{(P)} = \{(x, y) \in AOI | P_r(M, M_0) \geq P_{r,th}, M = (x, y, z)\} \qquad (1)$$

where P_r is the power of the signal received in a point $M(x, y, z_r)$. In accordance with the DTM-based multipath dynamic channel model the received power may be expressed by

$$P_r = P_{det} + P_{fad} = \frac{1+K}{K} P_{det} \qquad (2)$$

K being the extended Rice factor.

In other words the received power P_r is regarded as a combination of a deterministic power ($P_{r,det}$) and a fading power ($P_{r,fad}$) and is described by the extended Rice-model.

From (1) and (2) P_{det} may be assessed as

$$P_{det} \geq \frac{K}{1+K} P_{r,th} \quad (3)$$

Thus, the power domains $D^{(p)}$ in terms of the power of the deterministic (stable) part of the received signal are:

$$D^{(p)} = \left\{ (x,y) \in AOI \mid P_{det}(M, M_0) \geq \frac{K}{1+K} P_{r,th}, M = (x, y, z_r) \right\} \quad (4)$$

The number N_{det} of principal rays in the deterministic part of the received signal is determined by environmental particularities of the pair (M, M_0). Thus, each point M is characterised by the appropriate value $N_{det}(M, M_0)$. In practice N_{det} is in the order of one or ten, and it is assumed that in the whole area of interest

$$N_{det} \leq N_{max} \qquad (5)$$

N_{max} being a parameter of the desired cellular network.

From the (4) and (5) it follows that

$$\left. \begin{array}{l} D^{(p)} = \bigcup_{l=1}^{N_{max}} D_l \\ D_m \cap D_n = \varnothing, (m \neq n) \end{array} \right\} \quad (6)$$

where

$$D_l = \left\{ (x,y) \in AOI \mid P_{det}(M, M_0, N_{det} = l) \geq \frac{K}{1+K} P_{r,th}, M = (x, y, z_r) \right\} \quad (7)$$

It should be emphasized that in each domain D_l $(l = 1,2,\ldots,N_{max})$ one and only one l-ray channel model is realized.

In real high population urban environment the received signal is of multi-ray nature mainly due to mirror reflection from walls of buildings. Thus, domains D_l are considered as consisting of individual "reflection" (R_i) - areas where the signal reflected from a certain reflecting surface could be received (with predetermined location of the base station, of all reflecting surfaces and obstacles). Any deterministic ray can be received only inside its reflection. Any reflecting surface in couple with real or imaginary source bears its reflection.

Let M be the total number of reflections R_i in the AOI. Then the reflecting surface corresponding to reflection R_i as a_i and the source coordinate is denoted (x_{0i}, y_{0i}, z_{0i}). With the auxiliary areas $G^{(l)}_{i,j,k,\ldots}$ the following relations hold:

$$\left.\begin{aligned}
G_i^{(1)} &= R_i \cap \neg\left(\bigcup_{\substack{p=0\\ p\neq i}}^{M} R_p\right)\\
G_{i,j}^{(2)} &= R_i \cap R_j \cap \neg\left(\bigcup_{\substack{p=0\\ p\neq i,j}}^{M} R_p\right)\\
G_{i,j,k}^{(3)} &= R_i \cap R_j \cap R_k \cap \neg\left(\bigcup_{\substack{p=0\\ p\neq i,j,k}}^{M} R_p\right)\\
&\ldots
\end{aligned}\right\} \qquad (8)$$

where the number of indices i, j, k etc. is equal to the number of rays received in every point of considered area which for simplicity is limited by 3. Domains D_l are expressed as follows:

$$\begin{aligned}
D_1 &= \bigcup_{i=0}^{M} G_i^{(1)} \cap T_i^{(1)} \\
D_2 &= \bigcup_{\substack{i,j=0 \\ i<j}}^{M} G_{ij}^{(2)} \cap T_{ij}^{(2)} \qquad (9) \\
D_3 &= \bigcup_{\substack{i,j,k=0 \\ i<j<k}}^{M} G_{ijk}^{(3)} \cap T_{ijk}^{(3)}
\end{aligned}$$

where $T_i^{(1)}$ denotes an area where power received from the source located in the point (x_{0i}, y_{0i}, z_{0i}) is not less than $P_{r,th}$ in absence of obstacles:

Thus the received power is calculated as a combination of few reflection rays or as a combination of direct rays (P_0) and reflection rays ($R_i|_{i\neq 0}$).

$T_{ij}^{(2)}$ is the area where the over all power received from two sources located in points (x_{0i}, y_{0i}, z_{0i}) and (x_{0j}, y_{0j}, z_{0j}) is not less than $P_{r,th}$.

$T_{ijk}^{(3)}$ is the area where the over all power received from three sources is not less than $P_{r,th}$. Algorithms for formation of reflections R and areas T are described below.

The reflections R_i are determined by the following expression:

$$R_i = A_i \bigcap_{j=1}^{m} \neg B_j \bigcap_{k=1}^{m_i} \neg S_k^{(i)} \qquad (10)$$

where A_i is a sector of reflection for the i-th source, determined as shown in Fig. 2.

In Fig. 2 the sector of reflection is shown. The boundary of this sector is determined by the height h_i of reflecting wall a_i. (All heights: h_i, z_{0i}, etc. are measured from MT level). For $h_i \geq z_{0i}$, we obtain $l_2 = \infty$ and a boundary of R_i

coincides with the AOI boundary. It is assumed that $i = 0$ corresponds to LOS area, and R_0 coincides with the whole AOI.

In case of multiple sequential reflections the sector R_i could be determined by repeated application of the above procedure. The case of double reflections is shown in Fig. 3 with the reflected sector R_i in case of a double reflection.

Areas b_j in (10) are areas under a j-th building. $S_k^{(i)}$ is the shadow as cast by the k-th building, in which the i-th source is not to be received. These areas could be constructed by conventional means of computational geometry. Following the usual approach it is assumed that all buildings may be described by rectangular prisms with an arbitrary polygon in the base. The subtraction of $S_k^{(i)}$ in (10) should be implemented in two steps. First, shadows of buildings located inside A_i, are constructed, like for the building GHIJ in Fig. 4.

But some buildings may be located between the source and reflecting surface casting a shadow after reflection as, for instance, the shadow of the building CDEF in Fig. 4. In this case it is necessary to "reflect" such a building in a reflection surface and to construct a shadow of "reflecting building", as if it were a real one, using an imaginary source. In Fig.4 C'D'E'F' is a perimeter of "reflected" building and AA'"D"E"E'" is a part of its shadow inside the reflection from the imaginary source BS. Thus, such "reflected" buildings are preferably included in the logical intersection over k in (10).

Thus, in the above preferred embodiment the reflection rays (R) comprise also multiple reflections (R_i).

A further aspect of the determination of a power domain is diffraction. It is considered as a correction effect to the shadow, with the effect of "decreasing" the building shadow. First the diffraction caused by roofs of buildings will be considered with reference to Fig. 5, in which the diffraction by building roofs is shown. In Fig. 5

S is a source, ABCD is a building. Diffraction corrections are determined as follows. The distance EF (diffraction shortening d of the shadow in Fig. 5) is determined by the following system of equations:

$$\begin{cases} v = l_1 h d\left[\left(l^2 - Xd\right)^2 + h^2 d^2\right]^{-1} \cdot \left\{\dfrac{2}{\lambda}\left[\dfrac{1}{\left(l^2 - Xd\right)l_1} + \dfrac{1}{\left(l^2 - Xd\right)^2 + h^2 d^2 - l_1 l\left(l^2 - Xd\right)}\right]\right\}^{1/2} \\ F(v) = \left(l^2 + d^2 - 2dX\right)/\rho^2 \end{cases} \quad (11)$$

Here $F(v)$ is a Fresnel function for which the usual approximation was determined, λ is the wavelength. and ρ is used as follows:

$$\rho = \sqrt{P_0/(4\pi P_{th}) - h^2} \qquad (12)$$

where

$$P_{th} = P_{r,th} \cdot \frac{\lambda^2}{4\pi} \qquad (13)$$

In practice for small values of d the following approximation is valid:

$$d = \frac{v l^2}{l_1 h}\left[\frac{2}{\lambda} \cdot \left(\frac{1}{l_1} + \frac{1}{l_2}\right)\right]^{-1/2} \qquad (14)$$

with an inverse Fresnel function approximated in the following way:

$$\left.\begin{aligned} F^{-1}(a) &= \frac{0.225}{a}, \quad a < 0.5 \\ F^{-1}(a) &= 0, \quad 0.5 \le a < 1 \end{aligned}\right\} \qquad (15)$$

Diffraction on side building edges are considered in a similar way as shown in Fig. 6, in which the correction of diffraction on side building edges is explained. The same formulas (11) - (15) as above are used for calculation of shadow boundary shifts d in this case. In case of an arbitrary n conditions for areas $T^{(n)}$ can be written as follows:

$$\sum_{i=1}^{n} \frac{1}{(x-x_{0i})^2+(y-y_{0i})^2+z_{0i}^2} > \frac{1}{\rho^2} \qquad (16)$$

where r_i is a combination of all reflection factors corresponding to the i-th source. ρ is determined by (12). In case of two rays (16) is easily resolved for y:

$$y=\left[\rho^2-d^2-x^2 \pm \left(\rho^4+4x^2+d^2\right)^{1/2}\right]^{1/2} \qquad (17)$$

This equation determines one or two bounded contours, which are approximated by polygons with rather a great number of edges. In general the boundary of $T^{(n)}$ is determined as will be explained in the following.

The equation (16) is equivalent to an algebraic equation of degree $2n$, which can be solved for x for any arbitrary value of y. For a set of y_k with equal distance between each other all real solutions $x_i(y_k)$ of (16) are obtained by an appropriate numerical method. After that all points of $x_i(y_k)$ are linked to the closest points of $x_i(y_{k+1})$, if the difference between them is less then the difference between different $x_i(y_k)$. Points which are left free (not linked) by now will now be linked with each other. This operation leads to one or several bounded non-crossing contours. These contours determine a solution of the problem. If obtained contours are not bounded or are self-crossing r is increased and the above procedure is repeated.

An example of determining the required domains D_i is shown in Fig. 7. The only reflecting surface considered is a and its reflection R_i is dashed in Fig. 7. R_i corresponds to the whole AOI. $G_{01}^{(2)}$ coincides with R_i. $T_{01}^{(2)}$ is described by oval in Fig. 7. The contribution of $G_{01}^{(2)}$ in D_2 (doubly dashed) is determined by crossing of $G_{01}^{(2)}$ and $T_{01}^{(2)}$. So, a practical implementation of the described procedure consists in

elementary operations on areas (regions) and could be realized by conventional means of computational geometry.

Thus, in the above preferred embodiment the received power is calculated as combination of direct rays, reflection rays and diffraction contributions.

The determination of the power domain 2 in step 13 is thus completed and in the following step 14 the snr domain 3 is determined. The domain $D^{(snr)}$ corresponds to the snr GOS constraints snr_{th}. For a given base station 1 of the co-ordinates $M_0(x_0, y_0, z_0)$ the snr domain is defined as the area which satisfies

$$D^{(snr)} = \{(x, y) \in AOI \mid snr(M, M_0) \geq snr_{th}, M = (x, y, z_r)\} \qquad (18)$$

By definition

$$snr = \frac{P_r}{P_n} \quad (19)$$

where P_n is the noise power which is assumed to be constant in the AOI. From (18) – (19), for any point $M \in D^{(snr)}$ we get

$$P_r(M, M_0) = P_n \cdot snr(M, M_0) \geq P_n \cdot snr_{th} \qquad (20)$$

By virtue of equation (20), the calculation of $D^{(snr)}$ is reduced to calculation of the appropriate power domain with the power threshold

$$\widetilde{P}_{r,th} = P_n \cdot snr_{th} \qquad (21)$$

which is given by the refined DTM technique.

The determination of the snr domain 3 in step 14 is thus completed and in the following step 15 the Shannon domain 4 is determined. The Shannon domain $D^{(sh)}$ is defined as the one in which the basic Shannon requirement for reliable communications is satisfied. Precisely, for a given BS site $M_0(x_0, y_0, z_0)$

$$D^{(sh)} = \{(x, y) \in AOI \mid C(M, M_0) \geq R_s, M = (x, y, z_r)\} \qquad (22)$$

where R_s is the signaling transmission rate and C is the Shannon capacity of the radio channel for the pair (M, M_0).

The analytical expression of C for the DTM-based dynamic multipath channel model is given by

$$C(M, M_0) = W\left\{\ln\prod_{i=1}^{N_{sel}}\left[1 + \alpha_i^2 \frac{P_0}{P_n}\right] - \exp(\beta^2)Ei(-\beta^2)\right\} \qquad (23)$$

where

$$\left.\begin{aligned} \beta^2 &= K\left[\frac{P_0}{P_n}\sum_{j=1}^{N_{sel}}\alpha_j^2\right]^{-1} \\ Ei(-\beta^2) &= \int_{-\infty}^{-\beta^2}\frac{\exp(t)}{t}dt \end{aligned}\right\} \qquad (24)$$

Here P_0 is the transmitted power, $\alpha_i = \alpha_i(M, M_0)$ is the path loss for the i-th principal ray and W is the bandwidth. It is to be noted that (23) is a generalisation of the Shannon formula for the multipath channel with stable components in the received signal.

To obtain the required Shannon domain $D^{(sh)}$ without cumbersome point-to-point calculations the expression (23) is transformed into a function of SNR.

Since

$$snr = \frac{P_{det} + P_{fad}}{P_n} = \frac{1+K}{K} \cdot \frac{P_{det}}{P_n} \qquad (25)$$

where

$$P_{det} = \sum_{i=1}^{N_{det}} \alpha_i^2 P_0 \qquad (26)$$

it results from (24),(25), and (26) that

$$\beta^2 = K\left[\frac{P_{det}}{P_n}\right]^{-1} = \frac{1+K}{snr} \qquad (27)$$

Rewriting the last term in (23) and using (27) equation (28) holds

$$-\exp(\beta^2)Ei(-\beta^2) = \int_0^\infty \frac{\exp(-u)}{\left[u + \frac{(1+K)}{snr}\right]} du = F(snr) \qquad (28)$$

To transform the first term in (23) the approximation is made

$$P_i = \alpha_i^2 P_0 \cong \overline{P_i} \qquad (29)$$

where

$$\overline{P_i} = \frac{1}{N_{det}} \sum_{i=1}^{N_{det}} P_i = \frac{1}{N_{det}} P_{det} \qquad (30)$$

Then

$$\prod_{i=1}^{N_{det}}\left(1+\alpha_i^2\frac{P_0}{P_n}\right)\cong\prod_{i=1}^{N_{det}}\left(1+\frac{P_i}{P_n}\right)=\left(1+\frac{1}{N_{det}}\frac{P_{det}}{P_n}\right)^{N_{det}} \qquad (31)$$

Taking into account (28), (31), and (25) the required expression of C as a function of SNR is:

$$C\cong W\left[N\cdot\ln\left(1+\frac{1}{N_{det}}\frac{K}{K+1}snr\right)+F(snr)\right] \qquad (32)$$

i.e. $C=C_{N_{det}}(snr)$.

It is the basic formula for calculation of the required Shannon domain $D^{(sh)}$ by the threshold domain technique.

As mentioned above, $N_{det}=1,2,\ldots,N_{\max}$ in AOI. So:

$$D^{(sh)}=\bigcup_{l=1}^{N_{\max}}\widetilde{D}_l \qquad (33)$$

where $\widetilde{D}_l$ is the power domain corresponding to the appropriate power threshold value

$$\widetilde{P}_{r,th}(l)=snr_l P_n \qquad (34)$$

Here snr_l is a solution of the equation

$$C_l(snr) = R_s \qquad (35)$$

where the term on the left hand side is given by (32) with $N_{det} = l$.

Thus, the calculation of Shannon domain $D^{(sh)}$ is reduced to calculation of power domains $\tilde{D}_l$ with appropriate power thresholds $\tilde{P}_{r,th}(l)$ and step 15 is completed.

In this embodiment of the method of cellular network planning the last sub-step of determination of threshold domains consists in calculating the BER domain, i.e. step 16.

The refined DTM multipath channel model is used for deriving the required analytical expression for Shannon capacity and bit-error-rate, and for the high accurate calculations of cell components which will be explained in the following.

A BER domain $D^{(BER)}$ is defined as the one where the pre-specified information GOS constraint, given by a probability error threshold $P_{e,th}$, is satisfied.

$$D^{(BER)} = \{(x,y) \in AOI \mid P_e(M, M_0) \le P_{e,th}, M = (x, y, z_r)\} \quad (36)$$

$P_e(M, M_0)$ being an average error probability for the pair (M, M_0). Calculating the BER domain involves the following aspects:

The refined DTM-based multipath channel model is used with in general a few deterministic components considered as stable part of the received signal. The channel is treated as conventional Rice fading channel. The above solutions are expressed in terms of SNR. This permits to derive appropriate SNR-thresholds for pre-specified information GOS constraints and, consequently, reduce the problem to the determination of an snr domain, which was explained above.

After step 16 of determining the BER domain step 8 is completed by step 17, namely creating the cell area e.g. by intersecting the so far determined domains. An essential step of the cellular network planning procedure has thus been finished, and the cells 6 may be regarded as being of optimized shape and size. The degree of optimization strongly depends on the efficiency of the refined Digital Terrain Model (DTM), that is employed for determination of the above domains. In the following the difference between the refined Digital Terrain Model according to the invention and the well known Digital Elevation Model (DEM) for general surfaces such as atmosphere layers, groundwater tables etc. will be explained. In a DEM a real surface is approximated by a set of points in a three-dimensional Cartesian frame (X,Y,Z) - where the X- and Y-axis represent geographic coordinates (i.e. longitude and latitude, respectively) and the Z-axis represents the altitude above sea level. These (X,Y,Z)-triplets are preferably arranged in a grid based DEM with rows and columns. A single point can be accessed by its row and column number that corresponds to predefined geographic coordinates (i.e. latitude/longitude, UTM-coordinates, etc). Other structures which may be used for the elevation data are Triangulated Irregular Networks (TIN) and vector based structures.

In the refined DTM according to the invention terrain specific information is derived from elevation data for the area to be investigated (with the data being presented as a DEM) so as to create a set of digital terrain specific information data including the elevation data itself.

In the refined DTM each item in a map such as buildings, trees and streets is represented by a square, a polygon, etc., and it is stored in a memory. (The data are preferably stored in the memory as vector drawing data.) Additionally a specific height is added to the ground plan (square, polygon) of the item and is also stored in said memory. In a first preferred embodiment of the refined DTM the specific height is the average height of the building over its ground plan. In a second preferred embodiment of the refined DTM the specific height of the building is its maximum height. Other definitions of the specific height of a building will be obvious to persons skilled in the art. So a "2D+" model results that is slightly reduced in comparison to a complete 3D model, in that a specific height is stored as an attribute to the respective ground plan of an object rather than a third co-ordinate Z varying over the ground plan and requiring additional memory and processor performance.

A further simplification of the refined Digital Terrain Model is the neglect of foliage. The data in said DTM may thus be organized in three layers.

1. 2D layer of the ground plan of buildings, each building having a specific height assigned to it.

2. 2D layer of foliage and trees (circles or other curves), representing the size and location of the trees and foliage.

3. 2D layer of road network.

The coordinates are the same for all layers and thus layers are of the same size and correspond to each another.

With the refined DTM an exact and simple determination of the above power domain 2 ($D^{(P)}$), snr domain 3 ($D^{(snr)}$), Shannon domain 4 ($D^{(Sh)}$), and BER domain 5 ($D^{(BER)}$) becomes feasible, referring to a plurality of ground plans and specific heights of a plurality of buildings within said cell only (instead of a set of complete 3D data). Further, due to its efficiency the cell formation according to the present invention allows to overcome the main disadvantage of conventional cell formation, namely the overestimation of the required power, frequency, and technical resources for the cellular network because of an insufficient consideration of factors that limit cell formation in a high population urban environment.

The proposed method of cell formation in high population urban areas improves the efficiency of utilisation of power, frequency and technical resources. The improvements as accomplished by this invention as opposed to known cell formation technologies may be summarized as follows:

1. The method guarantees pre-specified GOS values (power, snr. and BER) in each cell, thus, making the CF process optimal. In particular, this is very important for call loss (CL) performance of mobile communications systems using the above cells. In such a case, there is only one cause of CL: no available traffic channel in a source cell for call blocking (CB) or in a target cell for call dropping (CD). In contrast, additional causes of CL arise in a real world situation where the conventional regular cells are currently used. Precisely, the above power GOSs are not satisfied in some domains within a regular cell. Extensive GSM-simulations have shown that these

additional factors of CL can essentially degrade the CL performance of such systems. This is a serious problem to overcome which arises in conventional regular cellular systems. There is no such problem when a method of CF is used in CNP.

2. The method accounts for the above key factors that constraint the CF in high population urban environment, i.e. it takes into account the complex topological structure of dense areas on the basis of a refined high resolution DTM (resolution of 2m or less); it accounts for the fine structure of electromagnetic (EM) fields in a complex urban environment by exact consideration of main physical mechanisms of EMW propagation (diffraction and multiple reflection); it relies on a realistic model of a multipath channel predictable with high accuracy in every point of the AOI for an arbitrary BS site.

3. The cell formation is performed automatically; no interactive iterative planning procedures or field strength measurements are used for cell formation; interactive simulation tools are used only as auxiliary means for visual illustration of the results and their analysis.

4. The DTM-based threshold domains technique of CF gives directly highly accurate cell boundaries under the predetermined GOS values, thus, avoiding the cumbersome point-to-point calculations in prior art CF processes.

While the invention has been described in terms of particular structures, devices and methods, those of skill in the art will understand based on the description herein that it is not limited merely to such examples and that the full scope of the invention is properly determined by the claims that follow.

Reference Numerals

1 base station

2 power domain ($D^{(P)}$)

3 snr domain ($D^{(snr)}$)

4 Shannon domain ($D^{(sh)}$)

5 BER domain ($D^{(BER)}$)

6 cell = intersection of all domains

7 read input data

8 cell formation step

9 base stations allocation

10 channel assignment

11 query: new traffic data available?

12 frequency assignment

13 determining a power domain ($D^{(P)}$)

14 determining an snr domain ($D^{(snr)}$)

15 determining a Shannon domain ($D^{(sh)}$)

16 determining a BER domain ($D^{(BER)}$)

17 creating the cell of all of the power domain, snr domain, Shannon domain, and BER domain

Claims

1. Method of communications network planning comprising the steps of:

forming (8) a plurality of cells (6) depending on grade-of-service requirements for each cell,

allocating (9) a base station (1) in each of said cells (6),

assigning (10) traffic channels to each of said cells (6),

assigning (12) frequencies to each of said cells (6),

wherein the step of forming (8) a plurality of cells (6) comprises the sub-steps of:

determining (13) a power domain (2, $D^{(P)}$) for each cell (6), which includes all points for which the received power (P_r) is greater than a predetermined threshold power ($P_{r,th}$),

determining (14) an snr domain (3, $D^{(snr)}$) for each cell (6), which includes all points for which the signal-to-noise ratio (snr) is greater than a predetermined threshold signal-to-noise ratio (snr_{th}),

determining (15) a Shannon domain (4, $D^{(sh)}$) for each cell (6), which includes all points for which the channel capacity (C) is greater than a predetermined signaling transmission rate (R_s),

determining (16) a BER domain (5, $D^{(BER)}$) for each cell (6), which includes all points for which the error probability (P_e) is less than a predetermined error probability ($P_{e,th}$),

creating (17) the cell (6) as an area of the intersection of the power domain (2, $D^{(P)}$), snr domain (3, $D^{(snr)}$), Shannon domain (4, $D^{(sh)}$), and BER domain (5, $D^{(BER)}$).

2. Method according to claim 1, wherein the received power ($P_{r,th}$) is a combination of a deterministic power ($P_{r,th,det}$) and a fading power ($P_{r,th,fad}$).

3. Method according to claim 2, wherein the fading power ($P_{r,th,fad}$) is approximated by the extended Rice-model.

4. Method according to claim 2 or 3, wherein the received signal is calculated as a combination of direct rays (R_0) and reflection rays ($R_i|_{i\neq 0}$).

5. Method according to claim 2 or 3, wherein the received signal is calculated as combination of direct rays (R_0), reflection rays ($R_i|_{i\neq 0}$) and diffraction contributions.

6. Method according to any of claims 2 to 5, wherein the reflection rays (R) comprise multiple reflection rays (R_i).

7. Method according to any of the preceding claims, wherein the channel capacity (C) is a function of said signal-to-noise ratio (snr).

8. Method according to any of the preceding claims, wherein determining each of said power domain (2, $D^{(P)}$), said snr domain (3, $D^{(snr)}$), said Shannon domain (4, $D^{(sh)}$), and said BER domain (5, $D^{(BER)}$) is based on a plurality of ground plans and specific heights of a plurality of buildings within said cell.

9. Method according to claim 8, wherein each of said plurality of specific heights corresponds to the average height of each of said plurality of buildings.

10. Method according to claim 8, wherein each of said plurality of specific heights corresponds to the maximum height of each of said plurality of buildings.

11. Communications network system with a plurality of cells (6),

wherein the size of each of the plurality of cells (6) is determined by a power domain (2, $D^{(p)}$), a snr domain (3, $D^{(snr)}$), a Shannon domain (4, $D^{(sh)}$) and a BER domain (5, $D^{(BER)}$).

12. Communications network system with a plurality of cells (6) according to claim 11,

wherein each of the plurality of cells (6) corresponds to the intersection area of said power domain (2, $D^{(p)}$), said snr domain (3, $D^{(snr)}$), said Shannon domain (4, $D^{(sh)}$) and said BER domain (5, $D^{(BER)}$).

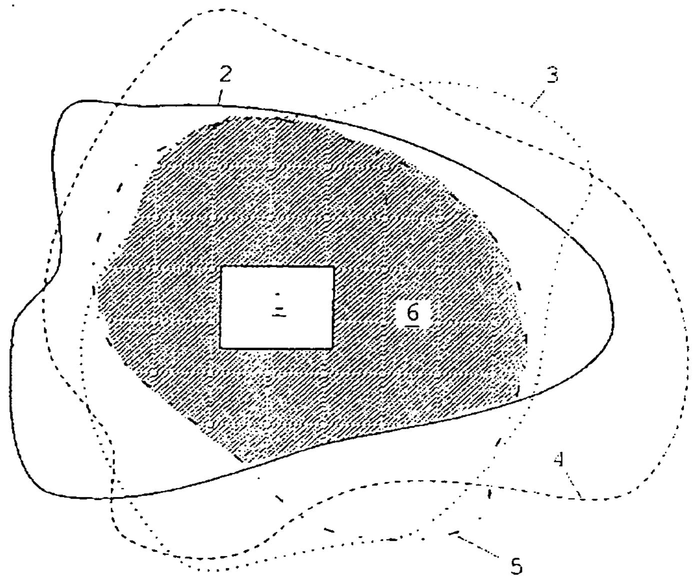


FIG. 1

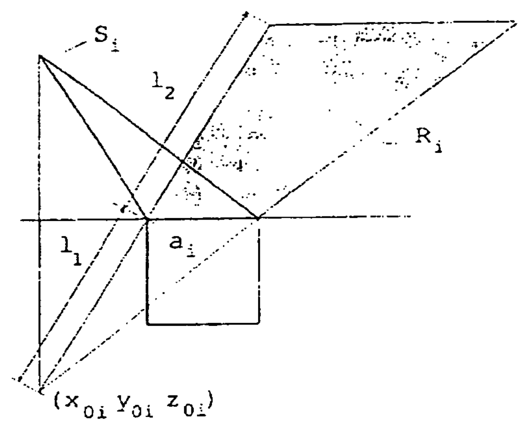


FIG. 2

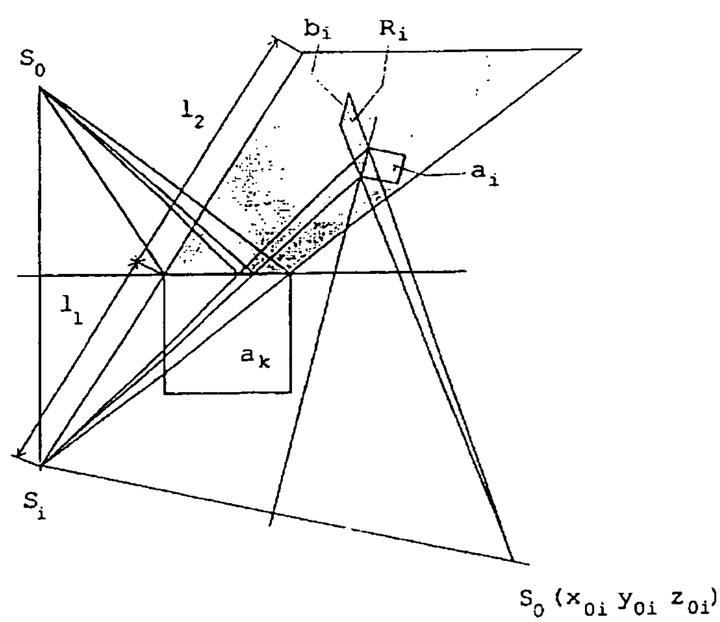
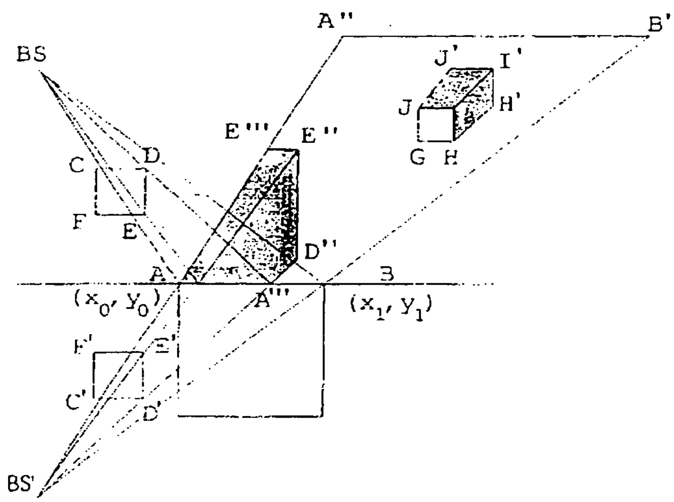


FIG. 3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B'
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G
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C
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A
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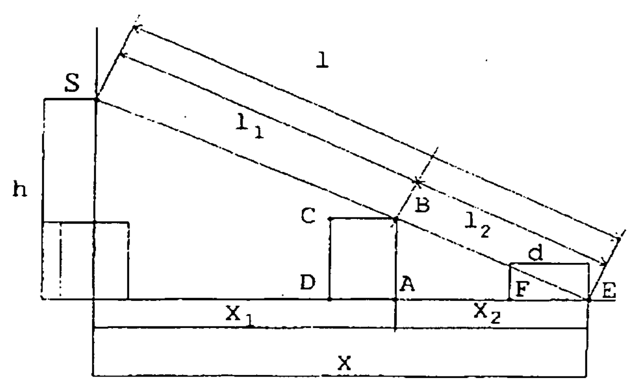
(x_1, y_1)
F'
E'
C'
D'
BS'

FIG. 4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l_1
h
C
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l_2
d
D
A
F
E
X_1
X_2
X

FIG. 5

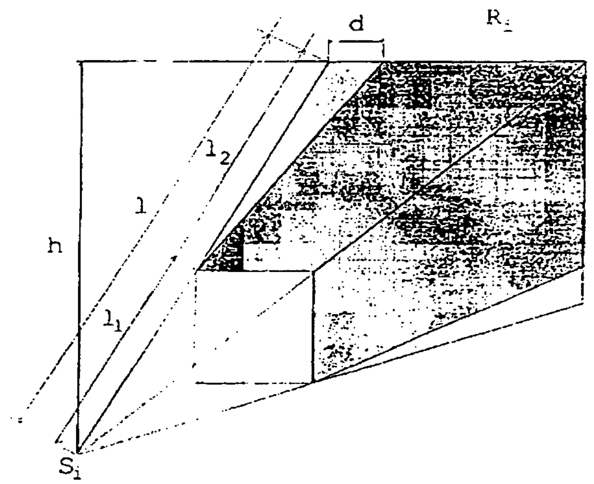

FIG. 6

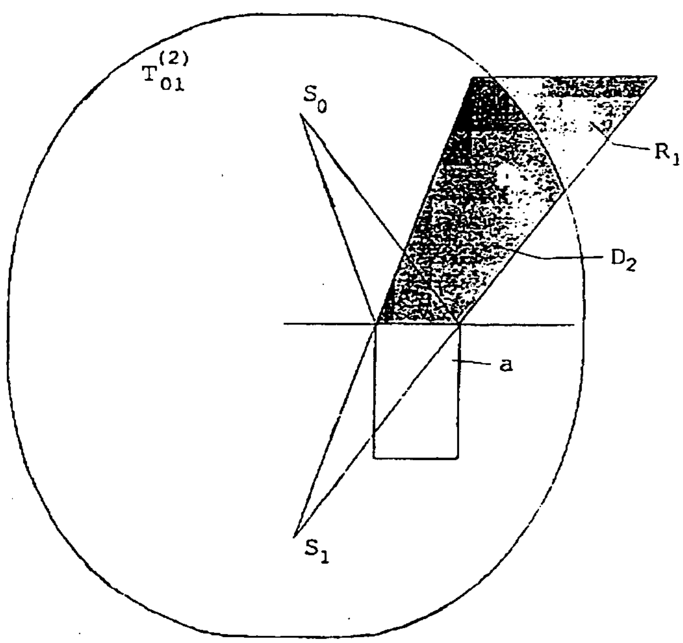

FIG. 7

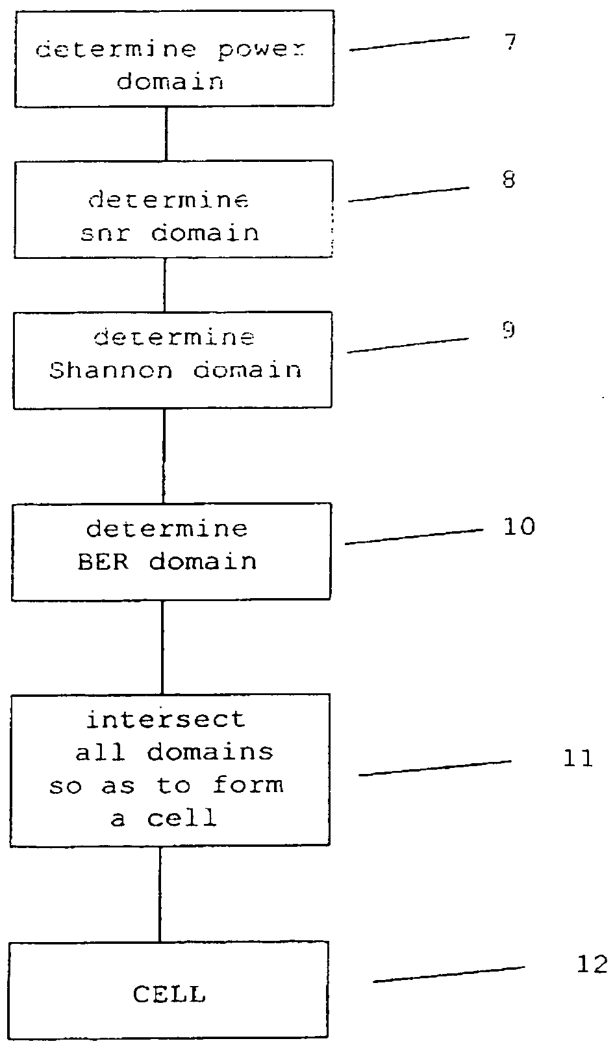
determine power domain
7
determine snr domain
8
determine Shannon domain
9
determine BER domain
10
intersect all domains so as to form a cell
11
CELL
12

FIG. 8

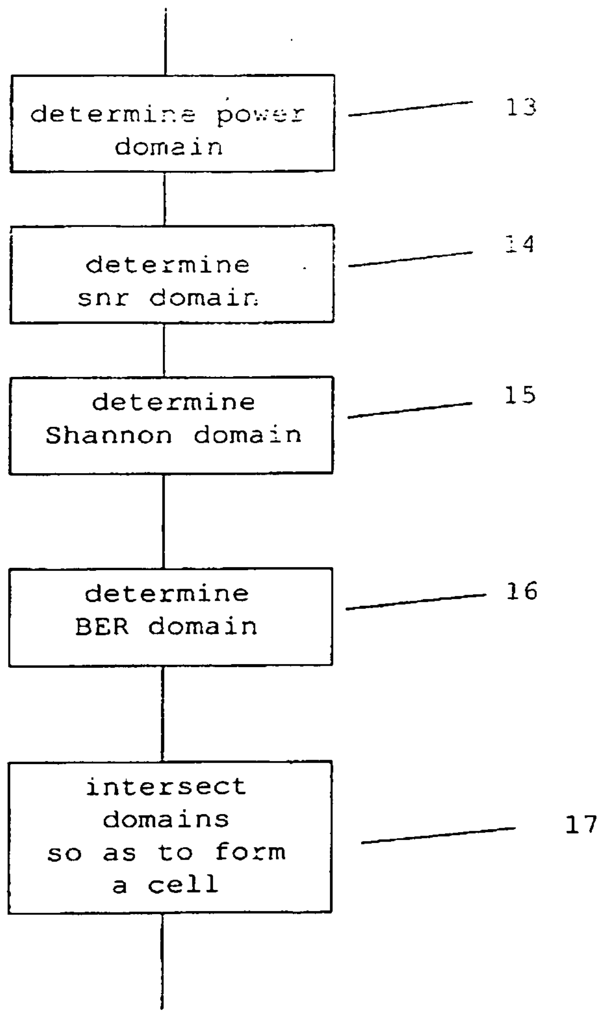
determine power domain
13
determine snr domain
14
determine Shannon domain
15
determine BER domain
16
intersect domains so as to form a cell
17

FIG. 9

INTERNATIONAL SEARCH REPORT

Intern ...al Application No
PCT/RU 00/00095

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04Q7/36

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 987 328 A (EPHREMIDES ANTHONY ET AL) 16 November 1999 (1999-11-16) column 2, line 55 -column 5, line 38	1-12
A	US 5 442 804 A (TEGTH ULF ET AL) 15 August 1995 (1995-08-15) column 2, line 51 -column 3, line 49	1
A	US 5 093 925 A (CHANROO KEITH A) 3 March 1992 (1992-03-03) column 2, line 63 -column 3, line 33	8-10

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 November 2000	08/12/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Bocking, P

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/RU 00/00095

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